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AUTOMATIC SPHERICITY INTERFEROMETER FOR TESTING LENS RADII

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U.S. ARMY ARMAMENT, MUNITIONS AND CHEMICAL COMMAND
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18. SUPPLEMENTARY NOTES

This project has been accomplished as part of the U.S. Army's Manufacturing Testing Technology Program, which has for its objective the timely establishment of testing techniques, procedures, and prototype equipment (in mechanical, chemical, and nondestructive testing) to ensure efficient inspection (cont)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Interferometer	Fringes	Convex
Digital radius scale	Master radius standards	Spherical wave
Radii	Test plates	MTT-Radius measurements
Transmission sphere	Concave	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The majority of lens radii measurements are made with test plates. This technique has the disadvantage of bringing the lens into direct contact with the test plate which can cause scratching of the surface and subsequent rejection of the test unit. In addition, test plate measurements are subjective because they depend on the experience and skill of the operator.

As an alternative, an automated interferometric technique was evaluated for its ability to measure lens radii. This method uses a fizeau (cont)

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18. SUPPLEMENTARY NOTES (cont)

methods for material/materiel procured and maintained by AMC.

20. ABSTRACT (cont)

interferometer with the following accessories: transmission sphere, lens mount, and digital radius slide. This technique, chosen for its ease of operation and noncontact approach, proved to be a more suitable approach to radius measurement than the use of test plates, because it eliminated both the subjectivity and contact associated with the test plates.

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TABLES

FIGURES

INTRODUCTION

This project involved the development and evaluation of an automated interferometer system for measuring the radius of curvature and surface figure of a spherical lens surface. An alternative to the use of conventional test glasses, the new interferometer system has the advantage of being a noncontacting technique. The conventional test glass technique involves physical contact between the test glass and the lens surface, a significant cause of lens scratching (particularly with inexperienced optical inspectors).

The equipment selected for this program was the Zygo MKII Interferometer with a Digital Radius Scale (DRS) and a Zygo Automated Pattern Processor (ZAPP).[1] To evaluate the new system for accuracy, reliability, and ease of use, a program was devised to use the interferometer system to measure the curvature and figure of various lenses and compare the results with conventional measurements.

DISCUSSION

Before the interferometer is used, it must be set up with its optical axis aligned parallel to the DRS. Additionally, the accuracy of the measurements is based on the straightness of the guide bar and the flatness of the surface on which the 3-axis mount slides. In our case, the horizontal plane offset is 8 inches; therefore, an angular error of 1 arc second will introduce an error in the measured radius of 40 micro-inches. In the vertical plane the offset is 2 inches; therefore, an angular error of 1 arc second will introduce an error of 10 micro-inches. (Details of the alignment procedure are provided by the manufacturer of the interferometer system.[2,3])

Samples of master radius test standards (table 1) obtained from an in-house optics shop were used to make radius measurements. The standards were selected to represent a cross section of lenses typically encountered in the Army's inventory. The optical shop foreman when asked about the technique used for the measurement of the standards replied that the masters do not need to be measured, which implied that the masters are perfect. Therefore the accuracy of the standards was not known, and there was no baseline to compare our measurements. For this reason, calibrated steel balls were obtained from the Metrology Laboratory (table 2).

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[1] However, any other interferometer with the same associated equipment can be used to take radius measurements like those presented in this report.

[2] "Zygo Interferometer System Operation - Maintenance Manual and Warranty," Zygo Corporation, Middlefield, CT, February 1980.

[3] "Zygo Radius Scale Operation - Maintenance Manual," Zygo Corporation, Middlefield, CT, April 1979.

Three radii of curvature measurements were made by different inspectors on each of the items in table 1, with the item under test being dismounted and remounted between measurements. In addition, three transmission spheres provided overlapping capability, and more than one was used to record the radius measurements. To select the optimum transmission sphere R/number to fill the aperature of a concave or convex surface, the R/number of the surface is calculated by the following formula:

$$\text{R/number} = \frac{\text{Radius of curvature of surface under test}}{\text{Clear aperture of surface under test}}$$

The transmission spheres used in this program were the f.75, f1.5 and the f3.3.

The procedure for making the radius measurements is straightforward and easy to learn without experience on the interferometer. An additional advantage of this method is that the test item does not come into contact with the transmission sphere. The procedures (used in this program) may have some elements peculiar to the Zygo interferometer, but in general they apply to any interferometer.

In the first step, the transmission sphere is placed in the accessory receptacle of the interferometer and aligned with the auto-align system. The test lens is mounted in the self-centering element holder so that the lens surface faces the interferometer aperture. The self-centering element holder is mounted in a 3-axis mount attached to the DRS carriage.

The radius of curvature of either a concave or convex surface can be measured. The center of curvature of the test surface is interferometrically made to coincide with the focus of the spherical wave emanating from the transmission sphere in figures 1 and 3 (position 1). The Z-axis fine adjustment screw is adjusted to optimize the straightness of the fringes. Final adjustment of this screw is to be in a clockwise direction and is assured by moving through best focus if necessary (position 1). The DRS display is cleared and the mount and carriage assembly are translated to place the test surface at the focus of the output beam from the interferometer transmission sphere in figures 2 and 3 (position 2). The Z-axis fine adjustment screw of the mount is adjusted again to optimize the straightness of the fringes. Final adjustment is to be in a clockwise direction and is assured by moving back through best focus if necessary (position 2). The radius of curvature of the surface is now displayed on the digital readout. The sign display will be plus for convex samples and minus for concave.

The accuracy to which the radius of curvature of a high quality spherical surface can be determined is a function of three things:

1. The R/number of the test surface

2. The accuracy of judging fringe straightness

3. The resolution and accuracy of the radius slide readout

The R/number is defined as the radius of curvature of the test surface divided by the clear aperture of the test surface.

The DRS display is a half-thousandth resolution system; each increment of measurement increases the display reading by 0.0005 inches.

Assuming the ability to judge straightness to within 1/10 fringe, the graph in figure 4 shows the accuracy of radius measurements as a function of the R/number of the surface under test. For example, an R1.5 surface can be measured to 1 um, and an R/7 surface to 25 um (0.0001 inch).

The results from the radius measurements on the master radius standards, listed by inspector and the R/number of the transmission sphere in table 3, show that the readings are repeatable and consistent between inspectors. The results also indicate a discrepancy of 34 thousandths of an inch in the worst case and between 2 and 4 ten-thousandths of an inch typically. Since the radius standards were an unknown, steel calibration balls were obtained to further assess the capability of the interferometer system to measure radii (table 4). The results, compared to the actual reading in table 2, confirm the accuracy and resolution of the interferometer system.

Table 1. Master test lenses

Concave (in.)	Convex (in.)
-0.574	+0.574
-1.050	+1.050
-1.651	+1.651
-3.232	+3.232
-4.275	+5.251
-5.251	+6.256
-6.256	
-14.262	
-19.330	

Table 2. Calibrated steel balls

Nominal size (in.)	Measured size (in.)
0.500	0.5001
0.625	0.62484
0.750	0.74997
0.875	0.87498
1.000	1.00003

Table 3. Interferometer readings of radius test standards

Inspector	Transmission sphere	Test standard (in.)	Measured radii (in.)
1	f.75	-3.232	-3.2355
			-3.2355
			-3.2310
		-4.275	-4.2760
			-4.2755
			-4.2755
		-5.251	-5.2550
			-5.2555
			-5.2555
	f1.5	-3.232	-3.2355
			-3.2355
			-3.2355
		+3.232	-3.2355
			-3.2350
			-3.2355
		-4.275	-4.2750
			-4.2750
			-4.2755
		-5.251	-5.2550
			-5.2550
			-5.2555
	f3.3	-3.232	-3.2355
			-3.2355
			-3.2350
		+3.232	+3.2360
			+3.2355
			+3.2355
		-4.275	-4.2750
			-4.2755
			-4.2750
		-5.251	-5.2545
			-5.2545
			-5.2555
		+5.251	+5.2525
			+5.2525
			+5.2525

Table 3. (cont)

Inspector	Transmission sphere	Test standard (in.)	Measured radii (in.)
2	f.75	-0.574	-0.5730
			-0.5735
			-0.5735
		+0.574	+0.5735
			+0.5735
			+0.5735
		-1.050	-1.0495
			-1.0495
			-1.0495
		+1.050	+1.0490
			+1.0490
			+1.0490
		-1.651	-1.6520
			-1.6520
			-1.6520
	f1.5	-1.050	-1.0490
			-1.0490
			-1.0495
		+1.050	-1.0490
			-1.0490
			-1.0495
		-0.574	-0.5735
			-0.5730
			-0.5730
		+0.574	+0.5730
			+0.5730
			+0.5730
		-1.651	-1.6525
			-1.6525
			-1.6525
		+1.651	+1.6520
			+1.6525
			+1.6525
		-6.256	-6.2530
			-6.2525
			-6.2530

Table 3. (cont)

Inspector	Transmission sphere	Test standard (in.)	Measured radii (in.)
		-14.262	-14.2295
			-14.2300
			-14.2290
		-19.330	-19.3240
			-19.3245
			-19.3245
	f3.3	-1.050	-1.0495
			-1.0495
			-1.0490
		+1.050	+1.0485
			+1.0490
			+1.0490
		-1.651	-1.6525
			-1.6525
			-1.6525
		+1.651	+1.6525
			+1.6520
			+1.6525
		-6.256	-6.2525
			-6.2525
			-6.2525
		+6.256	+6.2535
			+6.2535
			+6.2535
		-14.212	-14.2290
			-14.2290
			-14.2290
		-19.330	-19.3245
			-19.3250
			-19.3245
3	f.75	-3.232	-3.2360
			-3.2360
			-3.2355
		-4.275	-4.2760
			-4.2755
			-4.2755

Table 3. (cont)

Inspector	Transmission sphere	Test standard (in.)	Measured radii (in.)
		-5.251	-5.2555
			-5.2555
			-5.2560
	f1.5	-3.232	-3.2355
			-3.2355
			-3.2355
		+3.232	-3.2360
			-3.2355
			-3.2355
		-4.275	-4.2750
			-4.2755
			-4.2750
		-5.251	-5.2555
			-5.2555
			-5.2555
		-6.256	-6.2525
			-6.2525
			-6.2530
		-14.262	-14.2285
			-14.2285
			-14.2285
		-19.330	-19.3250
			-19.3245
			-19.3250
	f3.3	-3.232	-3.2355
			-3.2360
			-3.2360
		+3.232	+3.2350
			+3.2355
			+3.2355
		-6.256	-6.2525
			-6.2525
			-6.2525

Table 3. (cont)

Inspector	Transmission sphere	Test standard (in.)	Measured radii (in.)
		+6.256	+6.2540
			+6.2540
			+6.2540
		-14.262	-14.2285
			-14.2275
			-14.2280
		-19.330	-19.3250
			-19.3250
			-19.3250

Table 4. Interferometric readings of calibrated steel balls

Transmission sphere	Nominal diameter (in.)	Measured radii (in.)
f1.5	0.500	0.2500
		0.2500
		0.2500
	0.625	0.3125
		0.3125
		0.3125
	0.750	0.3750
		0.3750
		0.3750
	0.875	0.4375
		0.4375
		0.4375
	1.000	0.5000
		0.5000
		0.5000

CONCLUSIONS

This project proved that an interferometer and radius scale can be used to measure lens radii readily with little operator experience. The interferometric technique is a noncontact method of measurement which eliminates one of the major drawbacks of using test plates. An additional advantage of the interferometer is its reduced sensitivity to the level of skill of an operator, which avoids the problem associated with radius measurements using test plates. Test results show that the actual value of the test plates can introduce a sizable error.

The interferometer offers the additional benefit of being able to measure both the surface distortion and the radius of the test lens simultaneously. The interferometer can also be used to measure the surface figure of many other types of components (e.g., prisms, mirrors, and flats).

RECOMMENDATIONS

The interferometer is a worthwhile investment for any optical shop. Both versatile and easy to use, it eliminates the drawbacks associated with test plates, including the necessity to maintain a large inventory of various sizes. Test results show that the interferometer provides a more reliable measurement of radius than the test glasses. The only restrictions are the availability of transmission spheres and the length of the Digital Radius Scale used to make the measurements.

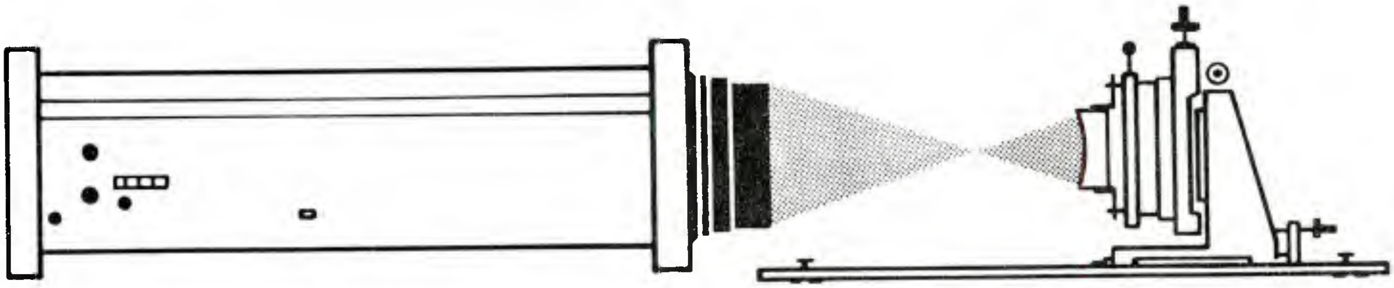

Figure 1. Interferometer setup for measurement of concave lens radii (position 1)

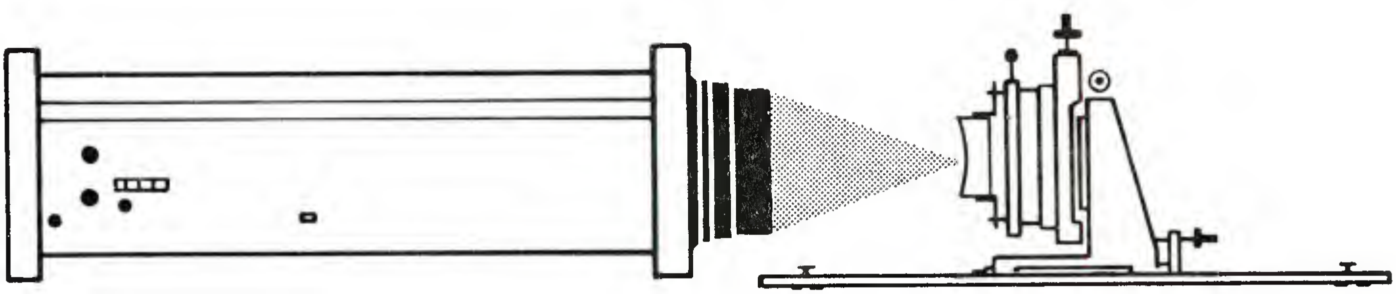

Figure 2. Interferometer setup for measurement of concave lens radii (position 2)

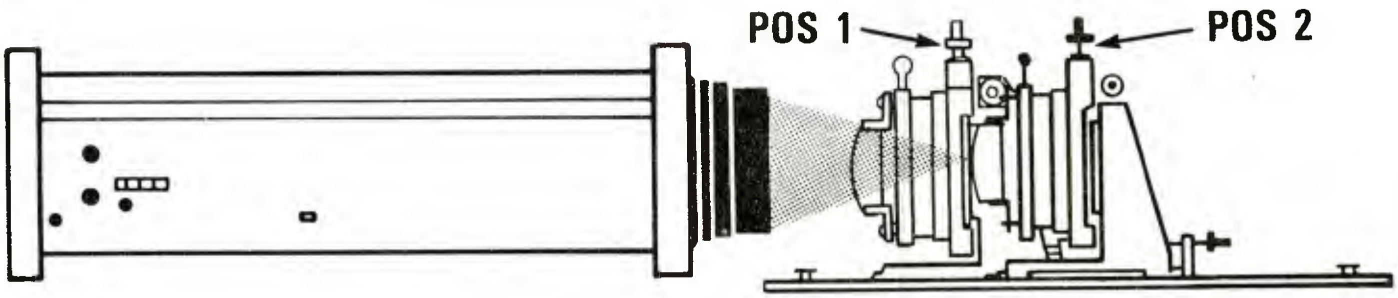

Figure 3. Interferometer setup for measurement of convex lens radii (positions 1 and 2)

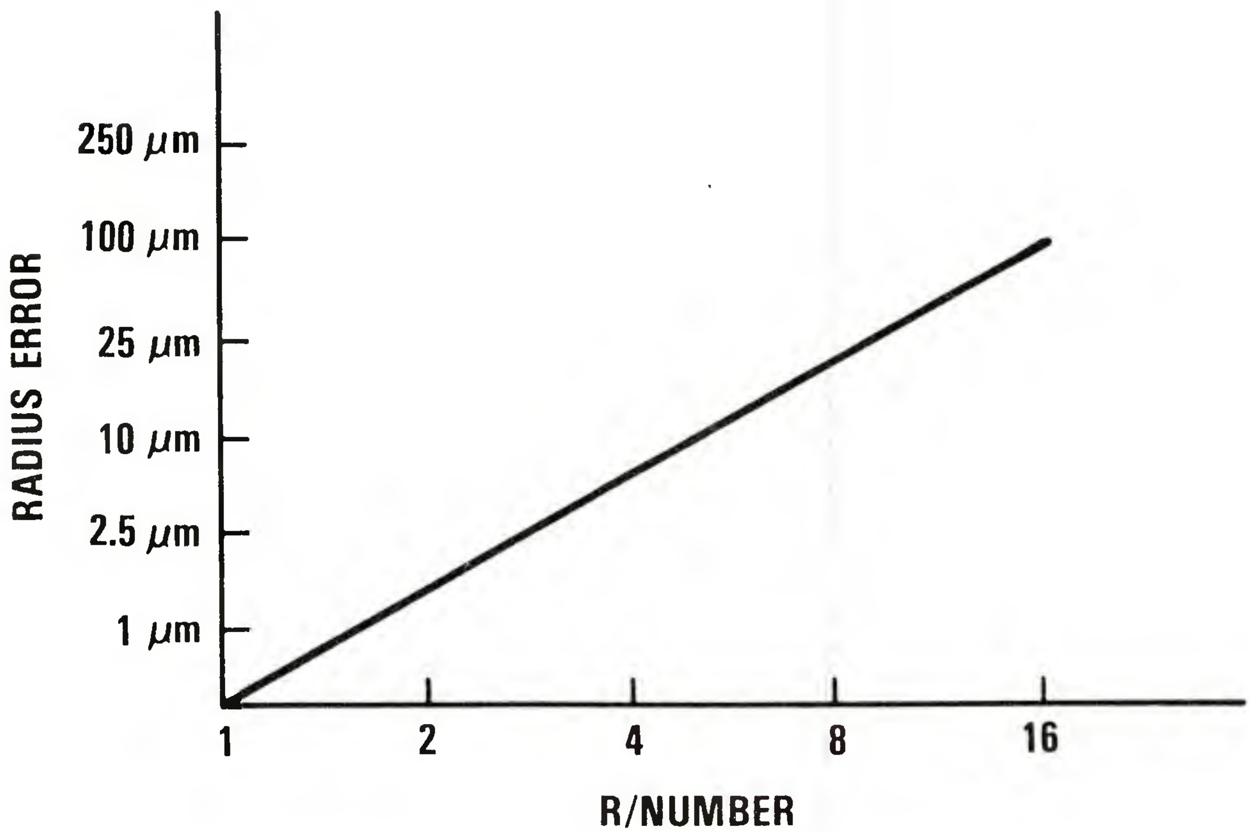

Figure 4. A graph of attainable system accuracy as a function of R/number

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